LORAN-C TIMING CALIBRATION OF CARIBOU, ME.

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Abstract

Results of timing calibrations made during the summer of 1986 on the Caribou, ME. LORAN–C transmitter with a mobile vehicle equipped with Global Positioning System (GPS and LORAN–C receivers are presented. At 0000 July 24, 1986, UTC(USNO MC) – LORAN(Caribou, 9960)= $-3.01\ \mu s \pm 0.10\ \mu s$**, and UTC(USNO MC) – LORAN(Caribou, 5930)=** $-5.07\ \mu s \pm 0.10\ \mu s$**.**

INTRODUCTION

The U.S. Naval Observatory (USNO) has been monitoring LORAN–C transmissions for 28 years. It publishes the results of its measurements weekly so that users of Precise Time and Time Interval (PTTI) may use LORAN–C transmissions to determine the time difference between a PTTI User clock and the Naval Observatory Master Clock (USNO MC).

The published measurements of the Observatory are corrected for various receiver delays, cable delays, etc. As time passes, however, the determinations of the values of the various delays become more and more uncertain because of changes in equipment, cabling, and changes in personnel. In addition, ambiguities sometimes arise concerning proper identification of the third cycle tracking point on the received LORAN–C signal.

In order to control the errors which may possibly result, the Observatory, from time to time, sponsors timing calibration trips to the vicinity of one or more LORAN–C transmitters in order to measure and determine the precise timing relationship between the USNO MC and a LORAN–C transmitter. This is a report of a timing calibration carried out in July 1986 by USNO on the 9960 East Coast and 5930 Canadian LORAN–C transmissions as emitted by the Caribou, ME. LORAN–C transmitter.

MEASUREMENT PROCEDURE

A detailed description of the measurement procedure has been previously given.[2] In general, the procedure consisted of identifying geodetic bench marks in the vicinity of the LORAN–C transmitter located at various multiples of one LORAN–C wavelength (3 Km) from the transmitter. Where geodetic bench marks could not be located at a suitable distance from the transmitter, another site was located on a map and a Mobile Electronic Laboratory (MEL) containing LORAN and GPS receivers driven to the site. The GPS receiver was then used to determine the latitude and longitude of the selected site. While the GPS measurement was being made, the time of reception of the LORAN–C signals from the transmitter was measured by a time interval counter. See Fig. 1.

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After completion of measurements at a site, the MEL was driven to the next selected site and the measurements repeated. In this manner, time of reception (TOR) measurements were made on the CARIBOU, ME. LORAN–C transmissions on the 9960 and 5930 repetition rates at a sequence of sites as approach was made to the CARIBOU transmitter.

Finally, the MEL was driven to the CARIBOU transmitter and measurements were made directly on the emitted signal as picked up by a whip antenna mounted on the MEL.

All measurements were made against portable cesium clock, PC1710.

MEASUREMENT SITES

Only two geodetic benchmarks at suitable sites from the CARIBOU transmitter were located. Several days were spent searching for other benchmarks; but it was later determined that one of the most desirable benchmarks had probably been destroyed or buried when a large mansion had been constructed. At other sites, benchmarks were located but were inaccessible to the MEL. For example, a benchmark was located at the top of a ridge but the "road" leading to the ridge top went up at a 55–60 degree grade which the MEL was not capable of handling. For this, and other mundane reasons, use of the GPS receiver to determine the latitude and longitudes of the map selected sites at which the LORAN–C TOR measurements were made, was essential to the success of this timing calibration. The two geodetic benchmarks located at suitable sites which were used are identified as "EASTON 1916 1983" and "HELLSTROM 1941".

Finding a benchmark can turn into an elaborate detective investigation. As Fig. 1 shows, the EASTON benchmark is located somewhere within a wheat field. Were it not for the friendly help of Mr. John F. Hoyt, on whose property the benchmark was located and who kindly gave us permission to enter upon his property, we might never have located the EASTON benchmark. See Figs. 2, 3, and 4. Table 1 is a list of the sites and benchmarks at which measurements of LORAN TOR were made. It also gives the GPS position as determined by the GPS receiver. It should be noted that the GPS measurements had to be made when the GPS satellites were available during an approximate 6 hour window. The need to plan LORAN TOR measurements around the times during which the GPS satellites were available was the controlling factor in determining when measurements were made. The sites are listed in a sequence in which the geometric distance to the CARIBOU transmitter monotonically decreases.

TABLE 1

GPS DERIVED POSITIONS

	SITE	LATITUDE				LONGITUDE			
		°	'	"		°	'	"	
1.	DET–A NAVASTRO	44	24	15.192	N	068	00	45.324	W
2.	HELLSTROM BM	46	53	21.716	N	068	16	13.545	W
3.	7 LAMBDA	46	37	18.456	N	067	52	03.054	W
4.	6 LAMBDA	46	39	00.768	N	067	51	58.776	W
5.	KEDDY'S INN	46	40	03.851	N	068	00	39.417	W
6.	EASTON BM	46	40	26.778	N	067	51	05.298	W
7.	5 LAMBDA	46	40	51.588	N	067	52	22.974	W
8.	4 LAMBDA	46	42	29.958	N	067	52	10.074	W
9.	3 LAMBDA	46	44	07.638	N	067	52	14.712	W
10.	2 LAMBDA	46	45	30.648	N	067	53	57.840	W
11.	1.5 LAMBDA	46	46	05.904	N	067	56	26.262	W
12.	1 LAMBDA	46	46	48.228	N	067	56	00.594	W
13.	Caribou Xmitter	46	48	27.199	N	067	55	37.713	W

The position given in Table 1 for the Caribou transmitter is the WGS 72 position, not a GPS derived position.

TIME OF RECEPTION (TOR) MEASUREMENTS

Two LORAN–C receivers were used. Receiver 1 (designated R1) was used in its wide band (WB) mode and tracked the end of the third cycle of the CARIBOU 9960 signals. Receiver 2 (designated R2) also was used in wide band mode but was set to track the end of the third cycle of the CARIBOU 5930 signals. The two receivers operated continuously; and, in order to insure good tracking while the MEL was in motion, the tracking point of each receiver was shifted six cycles into the LORAN–C signal waveform and the bandwidth changed to narrowband. Only after arriving at a site and upon placing the LORAN–C whip antenna on the benchmark or next to the GPS antenna, were the receivers switched to wideband and the tracking point shifted out of the LORAN–C waveform by six cycles. After the wideband, third cycle TOR measurements were made against PC1710, the two receivers were switched back to narrowband and the tracking point shifted back into the LORAN–C signal waveform by six cycles. This procedure avoided errors and ambiguities in cycle identification and also insured that there were no changes in receiver delays caused by turning the receivers off. It also permitted identification of potential measurement sites which were, because of local interference or other reasons, unsuitable for TOR measurements.

Table 2 gives the raw time of reception (TOR) measurements which were made.

DATA REDUCTION

The TOR measurements in Table 2 have to be reduced by subtracting out the propagation time for the geometric distance, the propagation phase correction as computed according to NBS Circular 573, the 9960 Caribou Emission Delay of 13797.2 microseconds for the R1 measurements, and the measured cable, antenna multicoupler, and receiver delays. For receiver R1, the measured combined cable, multicoupler, and receiver wideband delay is 19.05 microseconds. For receiver R2, the combined wideband delay is 19.14 microseconds. Finally, the 30 microseconds for the end of the third cycle must be removed.

The geodesic geometric distance of each site from the transmitter was calculated using the Sodano algorithm and the GPS measured positions in Table 1. Then the propagation phase correction was taken from a table which is generated by a computer program that calculates the phase correction according to the theory specified in NBS Cir. 573(Ref. 1). The assumed ground conductivity was 0.005 mhos/meter; and the permittivity was 15. The air index of refraction was taken as 1.000338 and the velocity of light as 299792458 meters/sec.

The results of the distance and phase calculations are given in Table 3.

TABLE 2

TIME OF RECEPTION (TOR) MEASUREMENTS

	Site	1986		UT	PC1710 - R1 (30,WB,9960) microseconds	PC1710-R2 (30,WB,5930) microseconds
1.	DET–A NAVASTRO	28	Jul	1832	14745.00	
				1854		950.42
2.	HELLSTROM BM	26	Jul	2032	13944.04	
				2034		149.19
				2251		149.13
				2252	13944.04	
3.	7 LAMBDA	23	Jul	1950	13922.03	
				1951		126.81
4.	6 LAMBDA	23	Jul	2034		117.15
				2035	13912.32	
5.	KEDDY'S INN	20	Jul	2042	13908.20	112.68
		21	Jul	1445	13908.09	112.66
		22	Jul	1233	13907.76	112.45
				1938	13907.75	112.58
		27	Jul	1943		113.11
				1944	13907.78	
		28	Jul	1223		113.10
				1224	13907.73	
6.	EASTON BM	22	Jul	2121		109.36
				2200		109.34
				2122	13904.65	
				2154	13904.65	
		23	Jul	0015		109.32
				0818	13904.66	
7.	5 LAMBDA	23	Jul	2108	13900.46	
				2120		105.25
8.	4 LAMBDA	23	Jul	2141	13891.55	
				2142		96.35
9.	3 LAMBDA	23	Jul	2214	13881.98	86.76
10.	2 LAMBDA	23	Jul	2259	13871.30	
				2300		76.14
11.	1.5 LAMBDA	23	Jul	2338		71.98
				2340	13867.15	
12.	1 LAMBDA	24	Jul	0016		68.38
				0017	13863.63	
13.	XMITTER (Direct from Whip Ant.)	25	Jul	1822		42.47
				1916	13837.41	

TABLE 3

CALCULATED DISTANCES AND PHASE CORRECTIONS

	Site	Geometric Distance D Kilometers	D/(c/n) μs	Phase Corr. (NBS573) μs	Total Phase Corr. μs
1.	DET-A NAVASTRO	267.198	891.58	1.87	893.45
2.	HELLSTROM BM	27.717	92.49	0.54	93.03
3.	7 LAMBDA	21.148	70.56	0.48	71.04
4.	6 LAMBDA	18.098	60.39	0.45	60.84
5.	KEDDY'S INN	16.811	56.10	0.44	56.54
6.	EASTON BM	15.922	53.13	0.43	53.56
7.	5 LAMBDA	14.663	48.93	0.41	49.34
8.	4 LAMBDA	11.879	39.64	0.40	40.04
9.	3 LAMBDA	9.099	30.36	0.37	30.73
10.	2 LAMBDA	5.849	19.52	0.36	19.88
11.	1.5 LAMBDA	4.483	14.96	0.37	15.33
12.	1 LAMBDA	3.094	10.33	0.42	10.75

For the direct measurements with the whip antenna probe under the Caribou transmitter antenna, a total of 35 μs consisting of 5.0 μs near field phase correction and 30 μs for the end of the third cycle, must be subtracted from the measurements. In the case of Caribou 9960, it was also necessary to remove a synchronization error of 0.2 μs between the on time 9960 group repetition rate generator and PC1710 and the Caribou Emission Delay.

RESULTS

After subtracting the above corrections from the Table 2 measurements, one obtains the values in Table 4 for the time differences PC1710 - LORAN(Caribou,5930) and PC1710 - LORAN(Caribou, 9960).

DIRECT MEASUREMENTS ON EMITTED SIGNAL

At the Caribou Xmitter, the timing of the LORAN–C signals for both the Caribou 5930 Master and the Caribou 9960 Slave were measured against PC1710. This measurement was done by manually superimposing, using an oscilloscope, a group repetition rate generator pulse (GRP) on the end of the third cycle of the Xmitter signal taken directly from the whip probe antenna, followed by a time interval measurement of the difference between PC1710 and the superimposed GRP pulse.

For the Caribou 5930 Master, Figs. 5, 6, and 7, show, for increasing oscilloscope sweep rate and vertical amplification, the relationship between the superimposed GRP pulse and the Caribou Master signal. Figs. 8, 9, and 10 show the relationship achieved for the Caribou 9960 Slave signal. Note that in both cases, there is no ambiguity as to where the Loran signal starts and the placement of the rising GRP pulse to coincide with the end of the third cycle. The timing measurements made on the GRP pulse thus synchronized with the emitted LORAN–C signals are given in Item 13, Table 2.

TABLE 4

REDUCED MEASUREMENTS FOR PC1710 - CARIBOU

	SITE	DATE 1986		UT	PC1710-L5930 μs	PC1710-L9960 μs
1.	DET–A NAVASTRO	28	Jul	1832	+7.83	
				1854		5.30
2.	HELLSTROM BM	26	Jul	2032		4.76
				2034	7.02	
				2251	6.96	
				2252		4.76
3.	7 LAMBDA	23	Jul	1950		4.74
				1951	6.63	
4.	6 LAMBDA	23	Jul	2034	7.17	
				2035		5.23
5.	KEDDY'S INN	20	Jul	2042	7.40	5.41
		21	Jul	1445	6.98	5.30
		22	Jul	1233	6.77	4.97
				1938	6.90	4.96
		27	Jul	1943	7.43	
				1944		4.99
		28	Jul	1223	7.42	
				1224		4.94
6.	EASTON BM	22	Jul	2121	6.66	
				2200	6.64	
				2122		4.84
				2154		4.84
		23	Jul	0015		4.85
				0818	6.62	
7.	5 LAMBDA	23	Jul	2108		4.87
				2120	6.77	
8.	4 LAMBDA	23	Jul	2141		5.26
				2142	7.17	
9.	3 LAMBDA	23	Jul	2214	6.89	5.00
10.	2 LAMBDA	23	Jul	2259		5.17
				2300	7.12	
11.	1.5 LAMBDA	23	Jul	2338	7.51	
				2340		5.57
12.	1 LAMBDA	24	Jul	0016	8.49	
				0017		6.63
13.	XMITTER (Direct	25	Jul	1822	7.42	
	from Whip Ant.)			1916		5.21

FINAL RESULTS

Because of the danger of near field phase deviations, the measurements made in and under the transmitter are used only as a check of the measurements made in the radiation zone. Using the PC1710 - LORAN–C(Caribou) values for the first ten radiation zone sites, one obtains:

$$\text{PC1710} - \text{L9960(Caribou)} = +7.02\mu s \pm 0.1\mu s \qquad (1)$$

and

$$\text{PC1710} - \text{L5930(Caribou)} = +5.00\mu s \pm 0.01\mu s \qquad (2)$$

at 0000 July 24, 1986.

The value for UTC(USNO MC) - PC1710 at 0000 July 24, 1986 as adjusted by portable clock closure value and the GPS timing measurements made on PC1710 while in the field was -10.03 μs. Using this value, the final timing calibration result is:

$$\mathrm{UTC(USNOMC)} - \mathrm{L9960(Caribou)} = -3.01\mu s \pm 0.10\mu s \tag{3}$$

and

$$\mathrm{UTC(USNOMC)} - \mathrm{L5930(Caribou)} = -5.07\mu s \pm 0.10\mu s \tag{4}$$

at 0000 July 24, 1986.

These values may be compared with an independent timing calibration of the Seneca, N.Y. 9960 Master transmitter, reported at the 1986 PTTI Applications and Planning Meeting:

$$\mathrm{UTC(USNOMC)} - \mathrm{L9960(Seneca)} = -3.43\mu s \pm 0.10\mu s \tag{5}$$

at 1611 Jul 14, 1986. Taking into account the fact that there are 14 days between the measurements made at the Seneca 9960 Master and the Caribou 9960 Slave, it is clear that the 9960 Northeast LORAN–C chain is correctly synchronized internally to better than 0.4 microsecond.

REFERENCES

1. Johler, J.R., Kellar, W.J., and Walters, L.C., "Phase of the Low Radiofrequency Ground Wave," NBS Circular No. 573, June 1956, National Bureau of Standards, Boulder, CO.
2. Keating, R.E., Lukac, C.F., Luther, G.H., and Charron, L.G., "Timing Calibration of the Northeast U.S.A. LORAN-C Chain(9960)," Proceedings of the Eighteenth Annual PTTI Applications and PLanning Meeting, December 2–4, 1986.

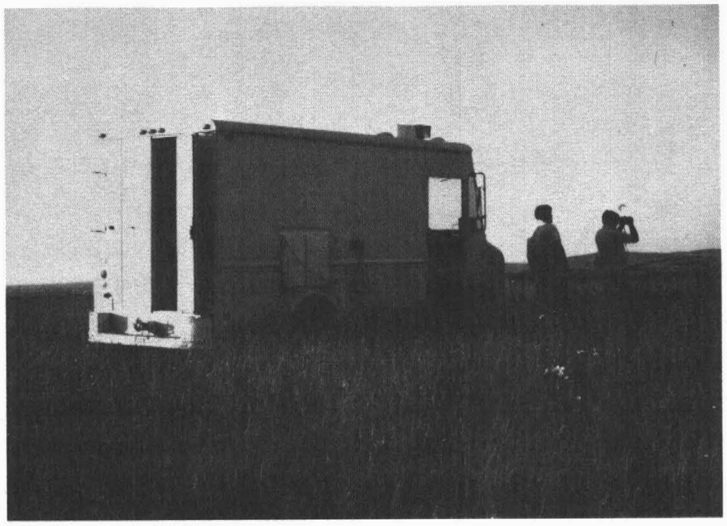

Fig. 1. Mobile Vehicle in wheat field in which EASTON benchmark is located.

Fig. 2. GPS and LORAN Antennae Setup at EASTON BM.

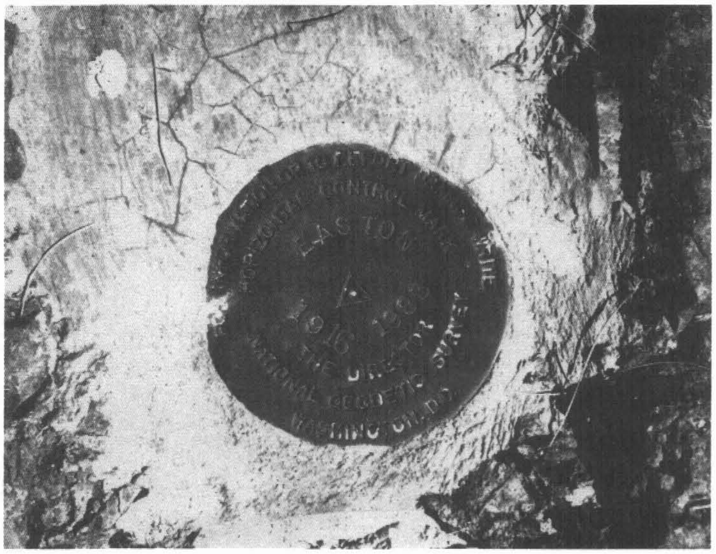

Fig. 3. EASTON Benchmark.

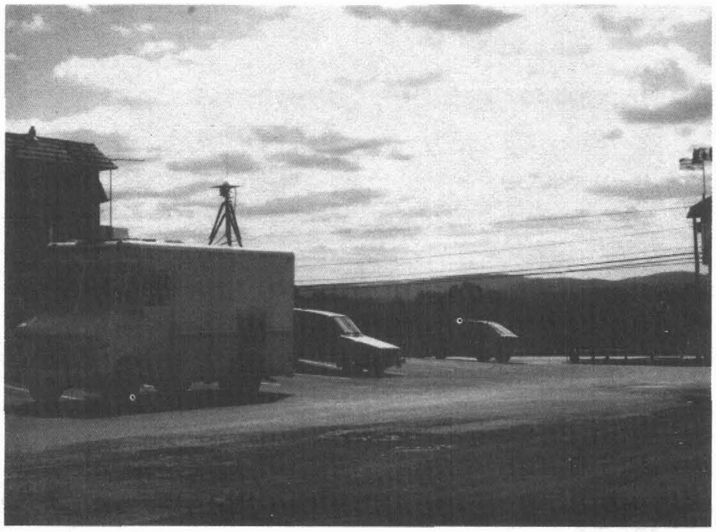

Fig. 4. GPS and LORAN Antennae Setup on top of MEL at Keddy's Inn.

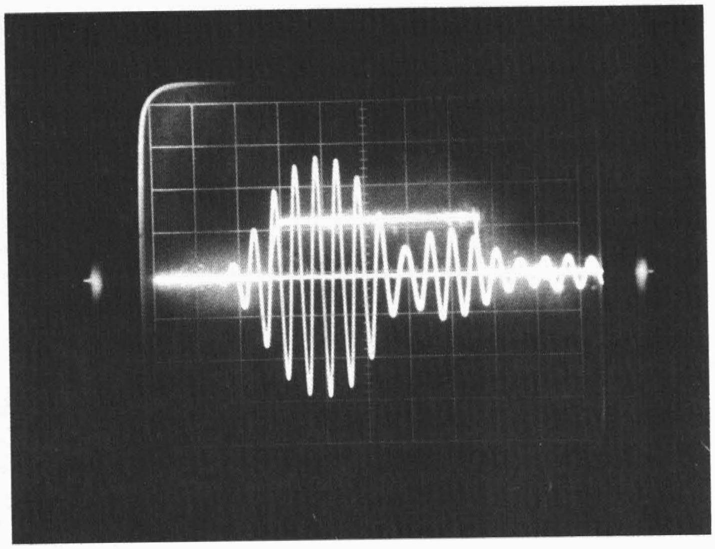

Fig. 5. Caribou 5930 Master with superimposed GRP pulse. Vertical oscilloscope setting for LORAN signal is 0.5 V/d; sweep is 20 microseconds/d.

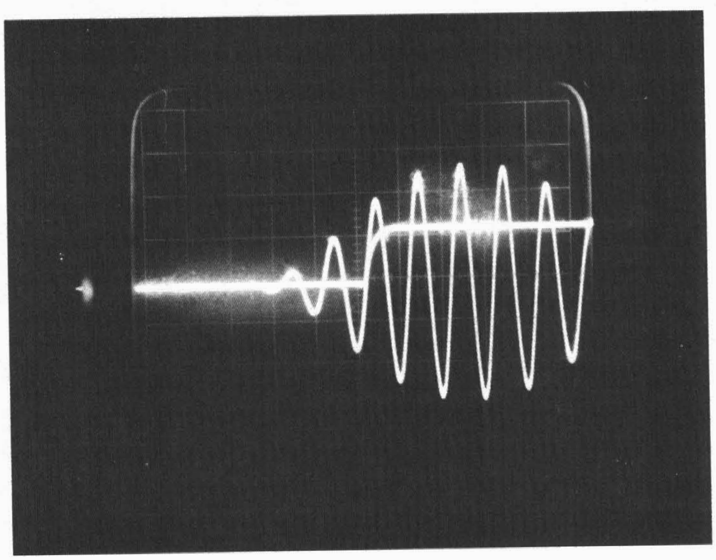

Fig. 6. Same as Fig. 5 but with sweep set at 10 microseconds/d.

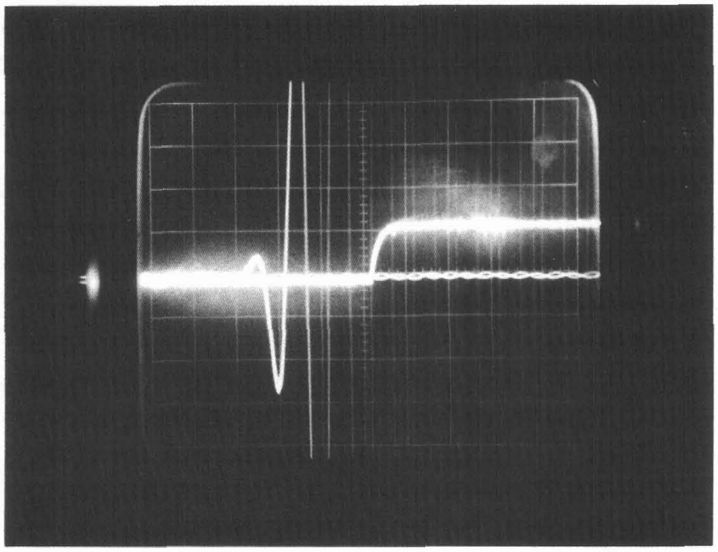

Fig. 7. Same as Fig. 6 but with oscilloscope vertical for LORAN signal set at 0.01 V/d. Note unambiguous start of Caribou 5930 Master waveform and the setting of the GRP pulse at the end of the third cycle.

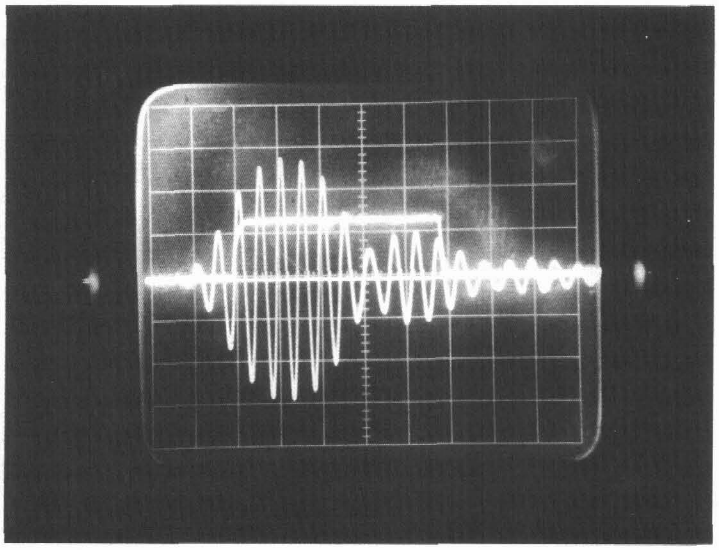

Fig. 8. Caribou 9960 Slave with superimposed GRP pulse. Vertical oscilloscope setting is 0.5 V/d; sweep is 20 microseconds/d.

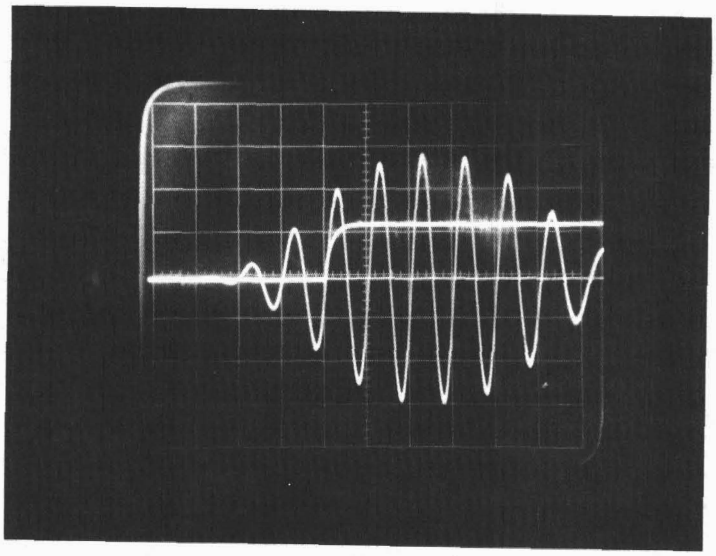

Fig. 9. Same as Fig. 8 but with sweep set at 10 microseconds/d.

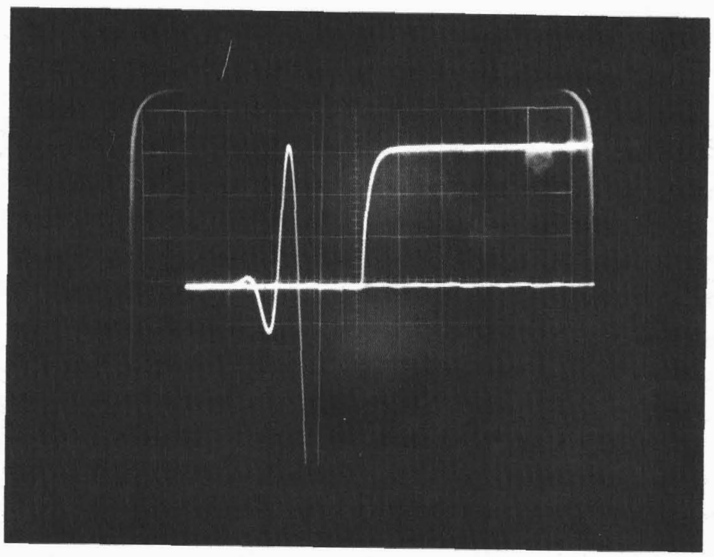

Fig. 10. Same as Fig. 9 but with vertical set at 0.01 V/d. Note unambiguous start of Caribou 9960 Slave waveform and the setting of the GRP pulse at end of the third cycle.